Development and Applications of Technology for Sensing Zooplankton

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LONG-TERM GOALS

The long-term goal of our research is to improve our ability to observe the ocean's plants, animals and their physical and chemical environment at critical scales that control how they live, reproduce and die.

OBJECTIVES

Our work is focused in two distinct, but related areas. The first addresses questions of the frequency of occurrence and characterization of thin layers in geographically separated, oceanographically diverse littoral environments. Our second research thrust involves continued development of measurement technology and models to support the use of multi-static, multi-frequency scattering in studies of small zooplankters and micronekton.

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The long-term goal of our research is to improve our ability to observe the ocean's plants, animals and their physical and chemical environment at critical scales that control how they live, reproduce and die.

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APPROACH

To address our first objective, we continued a series of low cost, "quick-look" surveys at several coastal sites characterized by a variety of physical and biological environments. Our aim is to assess whether these fine-scale phenomena are common and to obtain information on the ocean processes that lead to their formation, persistence, and eventual destruction. The surveys employ a TAPS-6 multi-frequency acoustical sensor to monitor vertical zooplankton distributions and abundances, and to estimate the size spectra of zooplankton and micronekton, all in relation to the local food and physical environment. We also use an ADCP mounted immediately next to the TAPS and a thermister chain with 1 or 2 meter spacing between elements. Our resolution of acoustical volume scattering for this work has been 12.5 cm in the vertical at intervals of a minute or two, depending on the planned duration of our deployment.

We continue to address our second objective with laboratory tank measurements and mathematical modeling of multi-static, multi-frequency scattering from a variety of simple zooplankton-like particles.

WORK COMPLETED

In support of our first objective, in prior years we occupied sites in both East and West Sound at Orcas Island in northern Puget Sound, WA. We have also made deployments at four sites on open linear coasts, including one just north of Oceanside, CA (Red Beach, Camp Pendleton); one near Yachats, OR (Cape Perpetua); and one in northern Monterey Bay near Santa Cruz, CA. We also collected data from Charleston Harbor, SC, from a location near Fort Johnston. During the current fiscal year, we completed our deployment at Cape Perpetua and collected several sequences of data from a location in the Goleta Bight between Goleta Pt. and Santa Barbara Pt., CA. We also recently instrumented a site near Rincon Island, southeast of Santa Barbara, CA. As a result of our work in two other projects that required deployment of similar instrument suites, we also have analyzed data for the presence of thin layers from the SAX-99 study site just south of West Destin, FL and from the Ogeechee River estuary in Georgia.

RESULTS

Thin layer structures have been observed at all of the ten sites examined to date but the percentage of time that they were present varied greatly. At some sites multiple, strong persistent layers lasted weeks. At other places, we detected only a small numbers of weak layers with durations of only a few hours. Early in the Cape Perpetua, OR deployment, in August 2002, an extremely intense low oxygen environment had just killed numerous fish and many of the benthic animals at a PISCO study area nearby our site. The hypoxic event persisted throughout most of our deployment period, weakening towards the end of August. It is uncertain whether this unusual nearshore hypoxia was due to advection or to the crash of a series of intense phytoplankton blooms (PISCO Coastal Connections, Vol. 2, 2003). The result, however, is that we detected only a few thin, weak zooplankton layers at Cape Perpetua, all at night when weak emergences of benthopelagic organisms were observed to concentrate in thin layers until they re-entered the sediments at dawn. The longest duration for a thin layer at this site was nominally 5 hours and it was modulated in depth by 5 m (peak-to-peak) internal waves with 20-min periods. Near the end of the month, weak thin zooplankton layers were detected during evening hours more frequently than they were earlier in the month. Although the physics

would possibly have supported good thin layers in normal circumstances, the unusual hypoxia during our occupation of this site appeared to suppress their formation.

Advective processes may play a part in determining some of the patterns observed, especially at the site in the Goleta Bight where weak, diffuse layers were observed from early May through mid-June. Many of the layers at Goleta exhibited more variation in thickness than has been observed at other sites. The layer structure was stronger, lasted longer, and had better vertical coherence in early May than it did in mid-June. This suggests that the peak productivity may have occurred at this site before we made the first Quicklook deployment at this location. Consistent cloud cover lasting until early afternoon, mid-day wind mixing, and relatively low upwelling likely contributed to episodically low phytoplankton and zooplankton levels, both of which were confirmed with net collections. Based on acoustical spectra measured at the Goleta site, there is evidence that very small gas bubbles from methane seeps sometimes dominate the acoustical scattering, especially at frequencies at the low end of the TAPS band (256-400 kHz). It appears that these bubbles, which are microns to tens of microns in diameter, rise from the sandy sediments in "clouds" and are advected about in mid-water before rising to the surface or being absorbed. Although there were no mapped seeps in the immediate area of our first Goleta site, we observed acoustical scattering spectra that are consistent with this hypothesis. When we moved the location to the east by a few km after a mooring battery change, small bubbles were visually observed breaking the surface as we left the new site. The presence of these bubbles should be noted and their impact on all proposed LOCO sensors and projects evaluated before using the Goleta Bight for future thin layers experiments.

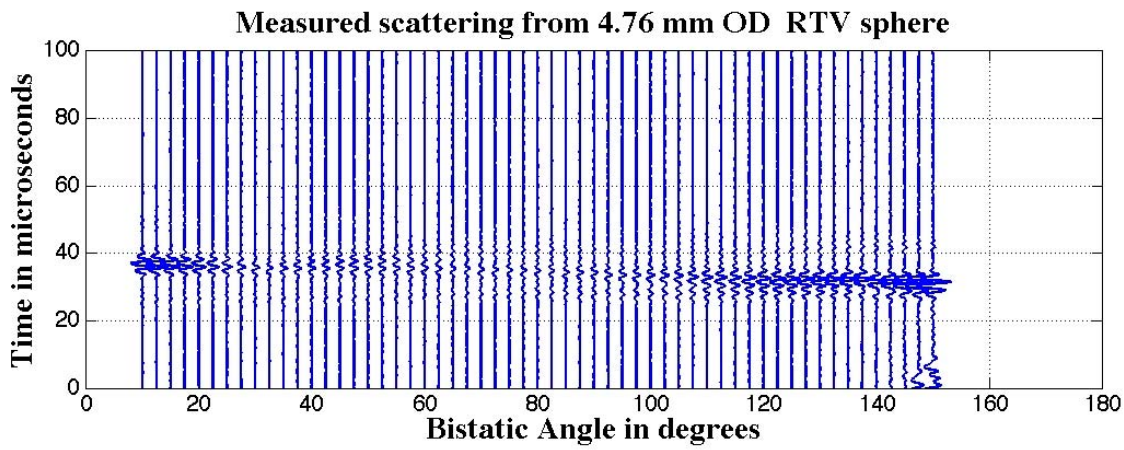
Our final deployment of the TAPS Quicklook sensors during 2003 was near Rincon, southeast of Santa Barbara, but northwest of Ventura, CA, in August 2003. This site was on a slightly wider coastal shelf, is slightly better protected from wind mixing than the Goleta site, and appeared to have smaller amplitude internal waves. This area is also thought to have fewer gas seeps though there is oil production nearby on-shore and on offshore platforms. Our TAPS data and direct sampling with nets indicated very low biomass for both phytoplankton and zooplankton in this area during August. Thin layers were episodic, infrequent, and usually the result of aggregation of foraging benthopelagic taxa at night.

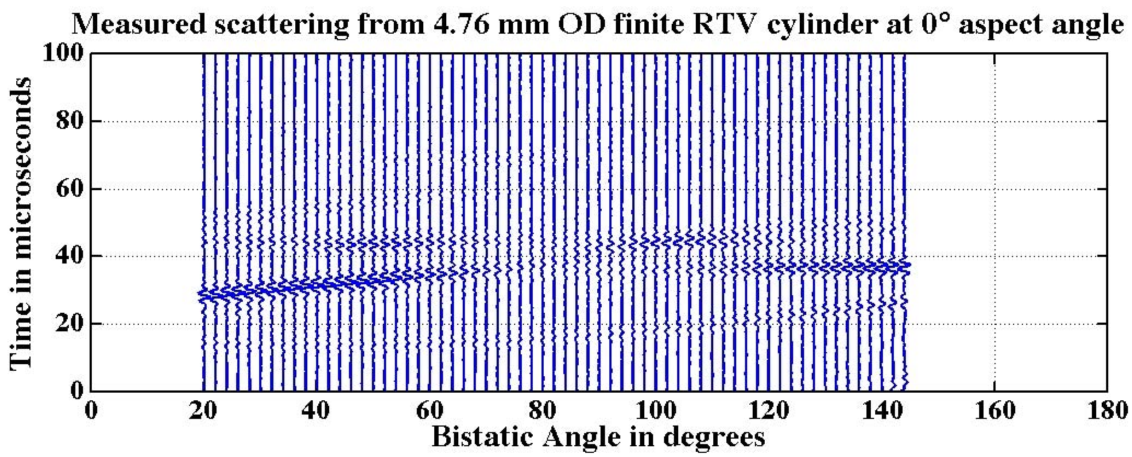
As a direct result of our "quick-look" surveys, important information is being added to a growing body of evidence that suggests a better knowledge of these phenomena is critical for understanding littoral ecosystems. By examining multiple environments, we are adding to our knowledge about how physical and biological factors lead to the formation of, and destroy, thin zooplankton layers.

Multi-static, multi-frequency methods

Most active bioacoustical methods in oceanography exclusively utilize the sound that is scattered by 180° from its original direction of propagation (backscattering). This is, for example, the mode used in an echo sounder when used to estimate fish biomass and in sonars. When a plane wave of sound encounters an object such as a fish, bubble, or zooplankter it is scattered in all directions, not just back towards the source. The directivity of the scattered sound and its spectral characteristics embed more information about the scattering object or organism than is contained in a backscattering measurement. In order to extract this information, including shape, size and physical properties, we are initially making laboratory measurements of scattered sound signals over a wide frequency band at many angles around some simple objects, e.g., fluid spheres, fluid cylinders with hemispherical end caps, etc.

We are also modeling forward scattering from these simple shapes in order to understand the physical echo-formation process and to work the "forward" problem in active bioacoustics. Working the "forward" problem is a necessary prelude to working the "inverse" problem, in which the measured temporal and spectral character of the sound is used to determine the character of the scatterer. Below, for two simple shapes, we compare the dependence of wideband scattered sound signals on the angle between the direction of the incident sound and that of the scattered sound energy. While we often work with the complex spectrum of these signals, the time signals embed the same information as the spectra and one can view these patterns as "fingerprints" of these two objects.





Wideband scattered acoustical signals, as illustrated in each panel, define "fingerprints" for each of the two shapes measured. The top panel illustrates multi-static scattering from a fluid sphere and the lower panel shows the same measurement for a fluid cylinder with hemispherical endcaps. A variety of modes can be identified and in these simple examples some of the discrete arrivals can be easily associated with the paths the sound takes as it propagates through and around the objects. The uniqueness of these "fingerprints" is that they illustrate multi-static scattering rather than measures of backscattering versus azimuth.

Our ultimate goal is to transition the understanding of the scattering processes that we gain in these simple laboratory experiments into an instrument for studying zooplankton at sea. By combining the multi-static information with the multi-frequency methods we have previously developed, we

anticipate that we can extract better estimates of size than can be done with multi-frequency measurements alone. This technique also offers a possibility for extracting shape and some important biophysical properties that may be useful in remote identification of the scattering organisms.

IMPACT/APPLICATION

Observation of aquatic animals in their natural environments continues to pose a major challenge in both biological oceanography and limnology. Critical processes in feeding, reproduction, growth, and predation occur at scales from fractions of millimeters up to scales that exceed the ambits of individuals. Our work is focused on the invention and development of new, high-resolution methods and technology for observing zooplankton and micronekton *in situ*. There is an increasing body of evidence suggesting that fine-scale vertical structures are ecologically important and, as a relatively new discovery, the mechanisms involved in their formation and utilization by different trophic assemblages are still largely unknown. Phytoplankton and zooplankton impact marine optics and underwater acoustics through both scattering and absorption. High production of phytoplankton may lead to the production of numerous small gas bubbles, which can have significant impacts on both optical and acoustical propagation, as well as measurements of ocean color. As many sensors used by naval forces rely on either optical or acoustical energy, the distribution of marine life potentially impacts current and future naval systems used in shallow water, where both mine detection and ASW operations must be conducted prior to engaging in expeditionary warfare.

TRANSITIONS

We continue to support several ONR principal investigators (e.g., Donaghay, McManus, Jumars, and Cowles) in the applications of our latest hardware and software developments to their own science programs. Similar low-level consulting activities are also ongoing with other several projects (Napp (NOAA/NMFS/AFSC), Roman and Boicourt (U of MD Horn Point), S. Smith (U of Miami / RSMAS) and Ortner (NOAA/AOML)). Sharon Smith's TAPS is being used in an ongoing NOAA project on a coral reef in the Caribbean. Acoustical hardware, which has resulted from our ONR support, has been deployed in the Coastal Gulf of Alaska by NOAA/AFSC personnel (Napp, *et al*) with funding from the Coastal Ocean Program (COP). New TAPS sensors have been recently delivered to NOAA's AFSC, to CSIRO in Australia (T. Koslow) and to Dr. M. Furasawa at the University of Tokyo. The CSIRO TAPS is being used in a multi-year ecosystem study on the western coast of Australia. Furasawa's TAPS is being used by his graduate students in fisheries research projects.

RELATED PROJECTS

Technology developed under this project is being extensively used by each of the groups listed immediately above. Additionally, we continue to provide technical support to Peter Jumars (U of Maine) and his students in their efforts to study the emigration and return of benthopelagic zooplankton in response to light and current cues. Progress is also being made in supporting publication of data collected by our co-PIs from South Carolina Wildlife and Fisheries in the Ogeechee Estuary. In part because of support received under this contract we have been able to make improvements in several methods for the analysis of high frequency acoustical data as it applies to understanding scattering from zooplankton. In particular, there have been several advances in estimating biomass distributions versus size for zooplankton of different basic shapes (e.g., copepods and mysids).

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HONORS/AWARDS/PRIZES

D.V. Holliday, BAE SYSTEMS, Department of the Navy's Meritorious Public Service Citation, awarded by the Chief of Naval Research, 2002.